REMARKS

Claims 1-6, 8-12, 15, and 31-41 are pending in the application.

Reconsideration of the claims is hereby requested.

<u>The Invention As-Claimed:</u>

As recited in claim 1, the invention provides a carbon nanotube device. The device has a substrate including an aperture extending from a front surface to a back surface of the substrate. The aperture is open only at the substrate front surface and back surface. At least one pair of electrically conducting contact pads is disposed on a selected one of the front and back substrate surfaces. The conducting contact pads in a given pair of pads are separated from each other by the aperture in the substrate surface on which they are together disposed.

A carbon nanotube catalyst region is disposed on top of each of the contact pads on the selected substrate surface, in alignment with an edge of the aperture. The catalyst regions are exposed at the selected substrate surface. At least one carbon nanotube extends across the aperture and is accessible through the aperture from both the front surface and the back surface of the substrate. Each end of the carbon nanotube contacts an exposed catalyst region on a contact pad at the selected substrate surface.

<u>Claim Rejections:</u>

Claims 1, 4, 6, 8, 9, 11, 15, 32, 34-37, and 40 were rejected under 35 U.S.C. §102(e) as anticipated by Shin et al., U.S. No. 6,515,339, (hereinafter "Shin").

Claims 10, 31, 33, 38, and 41 were rejected under 35 U.S.C. §103(a) as being unpatentable over Shin as applied to claim 1.

The Examiner suggested that Shin discloses a carbon nanotube device that is shown in Shin Figs. 4, 5A, 6A, and 26. The Examiner suggested that the Shin device comprises a substrate 10 including an aperture 16 extending from a front surface to a back surface with the aperture open only at the front surface and the back surface. The Applicants concur.

The Examiner suggested that the Shin device includes conducting contact pads 12 formed on one of the front and back surfaces and separated by the aperture; the Examiner here referred to Fig. 6B. The Applicants respectfully submit that this is not correct. Shin reference numeral "12" refers to catalyst regions, not contact pads. As explained by Shin, in a method for growing carbon nanotubes there is formed "a predetermined catalyst pattern 12 on a first substrate 10;" (Col. 5, lines 57-59). Instead, the Examiner pointed to Shin reference numeral 18 as being directed to carbon nanotube catalyst regions. But as explained by Shin, reference numeral "18" refers to "exposed surfaces 18 of the catalyst pattern 12," (Col. 5, lines 65-66). Shin forms apertures, "to expose the catalyst pattern 12 through the apertures 16," so that the catalyst is exposed at the side of the aperture, but not the top surface of the structure (Col. 5, lines 63-64).

Shin Figs. 3A-3D, 4, 5A-5B, and 6A-6B all illustrate aspects of the Shin carbon nanotube growth process referenced by the Examiner and refer to features of the resulting device consistently throughout the figures. No contact pads are shown in Shin Figs. 3A-3D, 4, 5A-5B, or 6A-6B. Reference numeral "12" consistently refers to a "catalyst pattern" and reference numeral consistently 18 refers to "exposed surfaces of the catalyst pattern" No reference numeral or text describing these figures refers to a contact pad.

Aside from what regions the Shin reference numerals point to, the Examiner suggested that Shin shows catalyst regions in alignment with the edge of the aperture and exposed at the selected substrate surface. The Applicants concur that the catalyst regions – "catalyst pattern 12" are in alignment with the edge of the aperture. But the Shin catalyst regions are not exposed at a selected substrate surface. As shown in Fig. 3C, Shin provides a "vertical growth preventing layer 14 on the first substrate 10, (Col. 5, lines 60-61). This growth preventing layer 14 is shown schematically in Fig. 4 with the catalyst regions in dotted outline to indicate that they are under the surface of the resulting structure on which the growth preventing layer is at the top. Fig. 5A shows this configuration in cross section, with the catalyst shown in a hatched region between upper and lower vertical growth preventing layers. Figs. 6A-6B show only the substrate 10 without the growth layer, to clearly illustrate the carbon nanotube growth between the catalyst regions 12.

Thus in Shin's device, catalyst regions are <u>not</u> exposed at a substrate surface as required by the claims. As shown clearly in Shin Fig. 3C and Figs. 4, 5A, and 5B, the catalyst regions are covered by a "vertical growth preventing layer 14." Shin makes clear that he requires such a vertical growth preventing layer, "so as to grow the carbon nanotubes in the horizontal direction," (Col. 3, lines 66-67).

The Examiner suggested that Shin teaches a carbon nanotube extending across the aperture and accessible through the aperture from the front and back surfaces of the substrate, with the nanotube contacting an exposed catalyst region on a contact pad at a substrate surface. As made clear in the description above, in the Shin device referenced by the Examiner, the Shin catalyst regions 12 are not exposed at a substrate surface. Instead, they are covered by a growth preventing layer 14. The Shin nanotube does not contact catalyst regions that are exposed at a substrate surface as required by the claims.

With regard to Shin Fig. 26 referred to by the Examiner, Shin Figs. 23-26 all illustrate Shin transistor devices (Col. 11, lines 54++). Shin explains that for these devices,

"a catalyst layer used as the catalyst is disposed under the electrode layers of source and drain," (Col. 11, lines 65-67). In all of these figures, the catalyst region is not on top of contact pads, the catalyst region is under a layer such that the catalyst region is not exposed at a substrate surface. Specifically with regard to Fig. 26, Shin explains that the, "catalyst is deposited on both ends of the guide and then an electrode is deposited thereon," (Col. 12, lines 38-59). The electrode is provided on top of the catalyst so that the catalyst is not exposed at a substrate surface. Similarly, Shin describes and illustrates, in Shin Figs. 15, 16, and 17, the synthesis of additional carbon nanotube devices in which contact pads are provided. As shown in Shin Fig. 16C, in this arrangement, a catalyst region is provided under a metal electrode. As above, Shin here employs the metal electrode as a vertical growth preventing layer.

These arrangements are in agreement with the configurations of Shin Figs. 3-6, and the Shin claims, in which Shin requires "a growth preventing layer on at least one of the first and second catalyst regions," (Claim 1). In contrast, as recited in claim 1, in the device of the invention, a catalyst region is disposed on top of contact pads and is exposed at a selected substrate surface; nothing is on top of the catalyst region.

The invention provides a discovery that a carbon nanotube device can be achieved by horizontal synthesis of carbon nanotubes between catalyst regions that are exposed on the top surface of a substrate. In other words, the invention provides a structure that is in direct contradiction with the vertical growth preventing layer employed by Shin to cover the surface of catalyst regions. In the invention, as recited in claim 1, each catalyst region is provided fully exposed at a substrate surface, on top of a contact pad, with each end of a nanotube contacting the catalyst region and contact pad exposed at a substrate surface. For example, as shown in Fig. 7C and Fig. 9 of the instant Specification, a catalyst region 26 atop each of two contact pads 16 is fully exposed, i.e., is not covered by other material layers. Then as shown in Fig. 7D of the instant application, a carbon nanotube 10 is synthesized between two of the exposed catalyst regions. Shin neither teaches nor suggests

that the catalyst regions could be exposed at a substrate surface as required by the claims, and instead requires that the catalyst regions be coated with a growth preventing layer or a contact pad.

In Shin's arrangement, a nanotube can only be synthesized from a side face 18 of a catalyst region layer under a vertical growth preventing layer, as shown in Shin Fig. 4. But it is found experimentally that the likelihood of success of Shin's arrangement in a nanotube growing across an aperture from a first catalyst side face to a second catalyst side face is very low. As nanotubes grow, they tend to flop around and then stick to a surface they eventually fall to and contact through Van der Waals forces. The Shin arrangement does not accommodate this behavior and requires that a nanotube "find" an end face of a catalyst region.

In contrast, the exposed catalyst regions of the invention recited in claim 1 enable nanotubes, as the tubes are synthesized, to directly access planar catalyst surfaces that are provided on top of contact pads exposed on a surface, and thus enable successful horizontal nanotube growth across an aperture. This arrangement overcomes the severe limitations of the Shin arrangement with a discovery that a vertical growth layer is not only unnecessary but deleterious to successful nanotube growth.

In this regard, Shin teaches against the arrangement of the invention. The Shin teaching could not produce the structure recited in claim 1. Shin does not allow for any catalyst region to be exposed at a substrate surface, and as a result does not allow for ends of nanotubes to contact catalyst regions that are on contact pads and exposed at a substrate surface. Shin requires the catalyst to be covered by a "growth preventing layer" or an electrode layer. The invention as recited in claim 1 requires the catalyst to be exposed on a substrate surface and provided on top of, not under, an electrode layer.

All of the dependent claims depend from claim 1 and include the limitations of claim 1 requiring carbon nanotube ends to contact catalyst regions that are disposed on top of contact pads and that are exposed at a substrate surface. Shin does not teach or suggest this requirement of all of the claims. As explained above, Shin teaches away from the limitations of claim 1, and therefore teaches away from the limitations of all dependent claims.

For clarity of the record, the Applicants here point to several additional limitations of dependent claims that are referred to by the Examiner. With regard to claims 9 and 11, the Examiner suggested that Shin discloses a substrate that is a membrane made of silicon dioxide having an aperture there-through and on a top surface of which is disposed contact pads and a catalytic region, referring to Shin Fig. 3B. With regard to claim 10, the Examiner suggested that Shin discloses a membrane, albeit a silicon oxide membrane rather than the required silicon nitride membrane.

As explained above, in Shin Fig. 3B, reference numeral "12" refers to "catalyst regions" that are covered by a "vertical growth preventing layer 14," as shown in Fig. 3C. There are no contact pads shown in Figs. 3B or 3C.

At Shin Column 6, lines 1-4, referred to by the Examiner, Shin suggests that, "various materials...may be employed as the first substrate 10 <u>and</u> the vertical growth preventing layer 14." Shin does not in any way teach or suggest the use of a membrane; in this sentence he is referring to substrate materials and companion materials that can be formed on the substrate as vertical growth preventing layers. The material silicon oxide is suggested as a vertical growth preventing layer for use with silicon or glass substrates; silicon oxide is not a substrate material. Glass coated with indium tin oxide (ITO) is similarly suggested as a substrate-vertical growth preventing layer pair, with glass forming the substrate and ITO forming the vertical growth preventing layer. Shin never once

teaches or describes how one could form a membrane structure or how one would integrate a membrane with a carbon nanotube as required by the claims.

With regard to claim 38, the Examiner suggested that Shin discloses a substrate having an aperture rather than a membrane having an aperture and supported by a substrate. Shin is devoid of any teaching or suggestion of a membrane, let alone a membrane with an aperture or a free-standing membrane supported by a substrate. For any membrane support, Shin simply does not even provide a membrane as required by the claims.

The membrane provided by the invention results from a discovery that a membrane structure can be employed to significantly reduce the processing required to form an aperture across which a nanotube is to be synthesized. Note in instant Figs. 7C-7D that the membrane 18 is significantly thinner than the substrate 12 which supports the outer edges of the membrane. At the location of the aperture 14 there can be employed a process for etching through the thickness of the membrane rather than the thickness of the substrate. With the use of a silicon dioxide or silicon nitride membrane, this discovery enables formation of conducting pads directly on the membrane as well as convenient etching through the membrane for producing a nanotube across an aperture and having access from both the front and back of a substrate. Shin is completely devoid of such teaching.

With regard to claim 15, the Examiner suggested that Shin discloses a plurality of pairs of contact pads, referring to Shin Fig. 7B. In Shin Fig. 7B, regions 12 are catalyst regions, not contact pads. Shin employs reference numeral "12" to refer to catalyst regions, not contact pads.

With regard to claims 35-36, the Examiner suggested that Shin discloses contact pads making connection to circuitry and a device on a selected substrate. The Applicants respectfully submit that in Shin Figs. 16B and 20-21 referred to by the Examiner, the contact pads make connection only to the nanotube and nothing else. At Shin Col. 10,

lines 50-63, referred to by the Examiner, Shin discuses a "spin valve single electron transistor," that is illustrated in Figs. 20-21. These are single devices having one source and one drain and incorporating carbon nanotubes. The contact pads are not connected to any circuitry or other devices on a substrate. Only the solitary nanotube device of Figs. 20-21 is described and taught.

With regard to claims 31, 33, and 41, the Examiner suggested that while Shin does not disclose the limitations of catalyst region thickness or covering required by these claims, it would have been obvious to optimize a catalyst region to come to these conditions as a manner of identifying a workable range in general conditions. Claim 31 requires catalyst regions that are less than about 2 nm in thickness and claim 41 requires a catalyst region layer coverage of no more than 17×10^{15} atoms/cm^2. Claim 33 requires that the catalyst region cover substantially an entire contact pad.

Shin does not teach or suggest a catalyst region covering any portion of a contact pad; Shin requires a catalyst region to be fully under a contact pad, in direct contradiction with the requirement of claim 33. For any catalyst region thickness or layer coverage, Shin does not teach providing a catalyst region exposed on a contact pad as required by all claims.

Further, The Applicants respectfully submit that the limitations of claims 31 and 41 are not workable ranges in general conditions, but rather, are structural configurations that result from discoveries relating to techniques for producing the carbon nanotube. As explained in the instant Specification at ¶¶42-43, the invention provides an understanding that as the catalyst layer thickness is increased, the diameter of nanotubes that are horizontally synthesized from the catalyst layer correspondingly increases, and above a threshold catalyst layer thickness, multi-walled, rather than single-walled, horizontal nanotubes are formed. For applications in which single-walled nanotube synthesis is desired, the invention provides the specification of a thin catalyst layer, e.g., of 2 nm in

thickness or less, as recited in claim 31, or 17×10^{15} atoms/cm^2, as recited in claim 41, for predictably and reliably forming single-walled nanotubes. It is a new and critical discovery of the invention that control of a catalyst layer to less than 2 nm in thickness or correspondingly, less than 17×10^{15} atoms/cm^2 in coverage an be employed to predictably, reliably, and repeatably produce single-walled nanotubes. Shin does not teach or even hint at this requirement.

Claims 2-3 and 5 were rejected under 35 U.S.C. §103(a) as unpatentable over Shin as applied to claim 1 above, and further in view of Brown et al., U.S. No. 6,297,063 (hereinafter "Brown").

The Examiner suggested that Brown teaches single walled and multi-walled nanotubes and teaches metallic nanotubes. For any nanotube conductivity and type taught by Brown, Brown and Shin cannot be properly combined to teach or suggest the nanotube device of the invention. Brown teaches a process for "in situ growth of nanowires between two circuit substrates," (Col. 4, lines 11-12). Shin requires vertical growth prevention layers over a catalyst region to carry out horizontal carbon nanotube growth along a single substrate. There is no possible way to combine the teachings of Brown and Shin. Shin prohibits the vertical nanotube growth required by Brown, understandably because Shin is interested in horizontal growth along a single substrate while Brown is interested in vertical growth between two separate substrates. There is absolutely no motivation to combine the teachings of Brown and Shin and any combination would result in inoperable structures. Neither Brown nor Shin, nor any proper combination of the two, teach or suggest the exposed catalyst region limitations of the claims.

Claim 12 was rejected under 35 U.S.C. §103(a) as unpatentable over Shin in view of Bradley et al., U.S. No. 20040043527 (hereinafter "Bradley").

The Examiner suggested that Bradley teaches a carbon nanotube device having a support structure holding a nanotube and aligned between a source of electrons and an electron detector for transmission electron microscopy. The Applicants respectfully submit that this is not the case. Bradley teaches exposing a nanostructure to an environment, e.g., an analyte, and detecting the analyte by measuring the difference between a first current through the device before exposure to the analyte and a second current through the device caused by interaction with the analyte (paragraph 56).

Bradley does not once teach or even mention transmission electron microscopy and the Bradley device has nothing at all to do with microscopy of any kind. Bradley is solely directed to a current measuring device for sensing an environment in which a nanostructure is provided. There simply is no teaching or even hint by Bradley of how one would conduct transmission electron microscopy on a nanotube. Shin similarly teaches and suggests nothing and no combination of the two can provide such.

Claim 39 was rejected under 35 U.S.C. §103(a) as unpatentable over Shin in view of Hunt et al., U.S. No. 20020167374 (hereinafter "Hunt").

The Examiner suggested that Hunt teaches that platinum and chromium are suitable materials for contact pads. The Applicants concur. But as explained in the previous response, the Hunt structure fails to meet the requirement of the claims that the structure be open only at the front surface and back surface. Further, like Brown, Hunt cannot be combined with Shin, because Shin requires vertical growth prevention layers over a catalyst region to carry out horizontal carbon nanotube growth along a single substrate.

With this discussion, the Applicants respectfully submit that the claims are in condition for allowance, which action is requested. If the Examiner would like to discuss the claims, she is encouraged to call the undersigned Agent at the phone number given below.

Respectfully Submitted

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